Pain Medicine, 20(2), 2019, 378–396
doi: 10.1093/pm/pny208
Advance Access Publication Date: 24 December 2018
Review Article

REHABILITATION SECTION

Effectiveness of Slump Stretching on Low Back Pain: A Systematic Review and Meta-analysis

Mohammadreza Pourahmadi, PhD, PT,[*] Hamid Hesarikia, MD,[†] Abbasali Keshtkar, MD, MPH, PhD,[‡] Hamid Zamani, MSc, PT,[*] Rasool Bagheri, PhD, PT,[§] Ali Ghanjal, PhD, PT,[¶] and Alireza Shamsoddini, PhD[||]

[*]Department of Physiotherapy, School of Rehabilitation Sciences, Iran University of Medical Sciences, Tehran, Iran; [†]Department of Orthopedic Surgery, Baqiyatallah University of Medical Sciences, Tehran, Iran; [‡]Department of Health Sciences Education Development, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran; [§]Neuromuscular Rehabilitation Research Center, Department of Physiotherapy, Semnan University of Medical Sciences, Semnan, Iran; [¶]Health Management Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran; [||]Exercise Physiology Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, Tehran, Iran

Correspondence to: Alireza Shamsoddini, PhD, Exercise Physiology Research Center, Life Style Institute, Baqiyatallah University of Medical Sciences, South Sheykh Bahayi Street, Molasadra Blvd, Vanak Sq, Tehran, Iran. E-mail: alirezaot@bmsu.ac.ir.

Funding sources: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Disclosure and conflicts of interest: The authors have no conflicts of interest to declare or financial relationships to disclose.

Abstract

Background. The slump test is a type of neurodynamic test that is believed to evaluate the mechanosensitivity of the neuromeningeal structures within the vertebral canal. The objective of this review was to investigate the effectiveness of slump stretching on back pain and disability in patients with low back pain (LBP). **Methods.** We searched eight electronic databases (PubMed/Medline, Scopus, Ovid, CINAHL, Embase, PEDro, Google Scholar, CENTRAL). The publication language was restricted to English, and we searched the full time period available for each database, up to October 2017. Our primary outcomes were pain and disability, and the secondary outcome was range of motion (ROM). **Results.** We identified 12 eligible studies with 515 LBP patients. All included studies reported short-term follow-up. A large effect size (standardized mean difference [SMD] = –2.15, 95% confidence interval [CI] = –3.35 to –0.95) and significant effect were determined, favoring the use of slump stretching to decrease pain in patients with LBP. In addition, large effect sizes and significant results were also found for the effect of slump stretching on disability improvement (SMD = –8.03, 95% CI = –11.59 to –4.47) in the LBP population. A qualitative synthesis of results showed that slump stretching can significantly increase straight leg raise and active knee extension ROM. **Conclusions.** There is very low to moderate quality of evidence that slump stretching may have positive effects on pain in people with LBP. However, the quality of evidence for the benefits of slump stretching on disability was very low. Finally, it appears that patients with nonradicular LBP may benefit most from slump stretching compared with other types of LBP.

Key Words: Low Back Pain; Neurodynamic Technique; Slump Stretching; Review; Meta-analysis

Introduction

Neurodynamic tests are frequently used in the clinical examination of patients with musculoskeletal pain disorders. The goal of these tests is to assess the mechanosensitivity of neural structures [1–3]. The slump test is a neurodynamic test that is believed to evaluate the mechanosensitivity of the neuromeningeal structures within the vertebral canal [3]. To perform the slump test, the patient is placed in an erect sitting position with the knees flexed to 90° and the legs hanging off of the side of the examination table [4,5]. The patient is asked to sit in a slouched position (thoracic and lumbar flexion with a posterior pelvic tilt) and is then requested to actively flex the cervical spine as far as comfortably possible [4]. The clinician/physical therapist then applies gentle overpressure to the upper thoracic and lower cervical spine and maintains this position throughout the examination [4]. The patient's ankle is then passively dorsiflexed to a neutral position while the knee is slowly passively extended until full extension is achieved [4,5]. Majlesi et al. [6] measured the sensitivity and specificity of this test and compared it with the straight leg raise (SLR) test. The results of the present study showed that the slump test was more sensitive (0.84) than the SLR test (0.52) in patients with lumbar disc herniation. The SLR was found to be more specific (0.89) than the slump test (0.83). Previous research has demonstrated that the slump test has diagnostic utility in differentiating between neural and non-neural structures, as pain of non-neural origin was not exacerbated by slump stretching [7].

During the last decade, several studies have used neurodynamic tests as treatment that can potentially resolve abnormal physiology within the nervous system [8]. There is no clear consensus on which group of low back pain (LBP) patients might benefit most from this neurodynamic treatment [8]. Maitland et al. [9] and Cleland et al. [10] demonstrated that patients with LBP and lower extremity pain who did not respond to directionally specific trunk exercises and those who did not present with radiculopathy did respond to slump stretching as an intervention. Furthermore, it has been suggested that patients with neuropathic pain or nerve root compromise would not benefit from neurodynamic treatment [11,12].

How the Intervention Might Work

There is no strong evidence to explain about mechanical and neurophysiologic mechanisms of slump stretching. Cowell and Phillips [13] suggested that slump stretching may disperse intraneural edema, restore pressure gradients, relieve hypoxia, and improve associated symptoms in neurogenic pain syndromes. The adhesion of neural tissues (e.g., dura, dural sleeve, and nerve root) to surrounding structures can prevent them from gliding freely and may result in a local increase in tension, producing irritation symptoms such as pain, burning, numbness, and tingling [5,14]. It has been reported that slump stretching can effectively reduce adhesion between the neural tissues and the surrounding connective tissues [15]. Moreover, slump stretching may reduce antidromic impulses generated in C-fibers at the dysfunctional site that result in the release of neuropeptides and subsequent inflammation in the tissues supplied by the nerve [10,16].

Literature Review

A recent systematic review and meta-analysis has looked at the effects of neural mobilization in healthy and LBP populations [17]. The authors concluded that there are positive effects from the application of neural mobilization to the lower body quadrant. Specifically, neural mobilization indicates moderate effects on flexibility in healthy people and large effects on pain and disability in patients with LBP [17]. The present study evaluated all neurodynamic treatments and did not focus on the slump stretching technique [17]. Because some relevant studies have not been included in Neto et al. [17] and other reviews [18–20], the objective of this investigation was to systematically review the literature to determine the effectiveness of slump stretching on back pain and disability in patients with LBP.

Methods

The study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [21]. The protocol of this systematic review was registered on the International Prospective Register of Systematic Reviews (PROSPERO; CRD42017081874, http://www.crd.york.ac.uk/PROSPERO/).

Search Strategy and Study Selection

A comprehensive electronic database search was conducted by one author (MRP) from inception to October 31, 2017, on the following databases: PubMed/Medline (NLM), Scopus, Ovid, CINAHL, PEDro, Google Scholar, and Cochrane Central Register of Controlled Clinical Trials (CENTRAL). The search terms used in PubMed are presented in Table 1. The search strategy for this review was a combination of medical subject headings (MeSH) terms and free text words. To optimize the strategy for each of the other databases, appropriate changes were made in the basic search strategy. Citation tracking and reference list scanning of included articles, six relevant reviews [17–20,22,23], and manual ahead-of-press searches were performed to identify other eligible studies. Moreover, hand searching of relevant journals was also conducted; these included the *Journal of Manual Therapy* (now known as the *Journal of Musculoskeletal Science and Practice*), *Journal of Physiotherapy*, and the *Indian Journal of Physiotherapy and Occupational Therapy.*

Eligibility Criteria

At the completion of the search, all references were imported into EndNote X8 software (Thomson Reuters, NY, USA), and duplicates were removed. Two reviewers (MRP and RB) screened titles and abstracts of all primary articles that met the search strategy in order to determine studies eligible for inclusion. If insufficient information was available in the title and abstract of an article, a full-text evaluation was undertaken. Then, the same two reviewers independently assessed the full text of potentially relevant nonduplicated articles. Disagreements were resolved through discussion between the reviewers. Studies were screened for selection according to the review objectives and Population, Intervention,

Table 1. Search strategy conducted in PubMed

#	Search	Record(s)
1	(neural) AND mobilization	108,333
2	(neural) AND stretching	388
3	(neural) AND tension	1,326
4	(neural or nerve) AND (excursion or gliding)	547
5	(#1–#4) AND low back pain [MeSH Terms]	14
6	(#1–#4) AND sciatica [MeSH Terms]	1
7	(neurodynamics) AND low back pain [MeSH Terms]	1
8	(neurodynamics) AND sciatica [MeSH Terms]	1
9	(slump) AND low back pain [MeSH Terms]	27
10	(slump) AND sciatica [MeSH Terms]	3
# of records after duplicates were removed: 44		

Comparison, Outcomes, and Study design (PICOS) criteria (Table 2).

Quality Assessment

Methodological quality was implemented by two reviewers (M.R.P. and R.B.) independently, considering the items according to the PEDro scale [26]. Items 2–9 relate to the internal validity of an article, and items 10 and 11 provide sufficient statistical information to enable appropriate interpretation of the results. Item 1 refers to the external validity of the trial and thus is not included in the total PEDro score (Table 3) [27]. Furthermore, primary studies that attained scores of $\geq$6 on the PEDro scale were considered high quality. Studies with a PEDro score of 4 or 5 were considered fair quality, and those with scores of $\leq$3 were considered low quality [27]. Cohen's kappa coefficient (κ) was used to measure the level of inter-rater agreement using a method developed for comparison of the level of agreement with categorical data, along with 95% confidence intervals (CIs; κ 0–0.20 = poor, 0.21–0.40 = fair, 0.41–0.60 = moderate, 0.61–0.80 = good, and 0.81–1 = very good) [28]. Consensus was sought in case of disagreement. The Centre for Evidence-based Medicine Levels of Evidence (March 2009; https://www.cebm.net/2009/06/oxford-centre-evidence-based-medicine-levels-evidence-march-2009/) was used to assess research design quality. The study designs were categorized by the research question that they answered and were given a level ranging from 1a (systematic review with meta-analysis) to 5 (expert opinion).

Data Extraction

Data extraction from the studies included was performed independently by two nonblinded reviewers (MRP and RB) using a standardized data extraction form. Details of the extracted data are presented in Table 4. Following the completion of this process, one author (MRP) double-checked the extracted data to avoid any omissions or inaccuracies.

Measures of Treatment Effect

The pooled effects of continuous variables were expressed as the standardized mean difference (SMD) if

Table 2. PICOS criteria for the study

Criteria	Inclusion
Population	The population was composed of adult patients ($\geq$18 years) of both genders with LBP. LBP was defined as pain on the posterior aspect of the trunk from the lower margin of the 12th ribs to the lower gluteal folds, with or without pain referred into one or both lower limbs that lasts for at least one day [24,25].
Intervention	Slump stretching is a neurodynamic treatment. During this stretching, the patient sits comfortably in a slouched position (thoracic and lumbar flexion with a posterior pelvic tilt) [4]. Afterward, s/he actively flexes the cervical spine as far as comfortably possible [4]. Overpressure is then applied to the upper thoracic and lower cervical spine, and this position is maintained throughout the treatment procedure [4]. Furthermore, knee extension and ankle neutral position (0° dorsiflexion) should be maintained during slump stretching [3].
Comparator	Other physical therapy interventions and sham or control group.
Outcomes	The primary outcomes of this systematic review were low back pain and disability. The secondary outcome was range of motion.
Study design	Clinical trials with concurrent comparison group(s) published in peer-reviewed journals with full text available in English; results obtained from theses/dissertations, conference proceedings, abstracts, and websites were excluded. In addition, studies assessing review articles, case series studies, and case reports were excluded [25].

the same outcomes were used in the included studies. If continuous outcome measures differed between studies, the pooled effects were also expressed with SMDs, but the outcome measures were first converted to a 0–100 scale [29]. All outcome variables were continuous. The effect sizes were calculated using the sample size, mean, and standard deviation, both at baseline and post-treatment for all groups (treatment and comparison). For the measurement of effect sizes, we defined three levels: small (SMD $<$ 0.40), medium (0.40 $\leq$ SMD $\leq$ 0.70), and large (SMD $>$ 0.70) [30]. A clinically important effect was considered when the magnitude of the effect size was at least medium [31].

Assessment of Heterogeneity

Heterogeneity among primary studies was evaluated using the I^2 statistic and the Q test (χ^2), as recommended by the Cochrane Handbook for Systematic Reviews of Interventions [32]. We interpreted the I^2 statistic using the following guide: 0–40% = no important heterogeneity, 30–60% = moderate heterogeneity, 50–90% = substantial heterogeneity, 75–100% = considerable heterogeneity [29]. We considered heterogeneity before conducting pooled analysis. When I^2 values were higher than 50% and there was overlap between the CIs in visual inspection of the forest plot, we combined the results into a meta-analysis using a random-effects model [27].

Table 3. The PEDro 11-item scale (from PEDro database, www.pedro.org.au)

1. Eligibility criteria were specified.	no ☐ yes ☐ where: ___
2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received).	no ☐ yes ☐ where: ___
3. Allocation was concealed.	no ☐ yes ☐ where: ___
4. The groups were similar at baseline regarding the most important prognostic indicators.	no ☐ yes ☐ where: ___
5. There was blinding of all subjects.	no ☐ yes ☐ where: ___
6. There was blinding of all therapists who administered the therapy.	no ☐ yes ☐ where: ___
7. There was blinding of all assessors who measured at least one key outcome.	no ☐ yes ☐ where: ___
8. Measures of at least one key outcome were obtained from >85% of the subjects initially allocated to groups.	no ☐ yes ☐ where: ___
9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome were analyzed by intention to treat.	no ☐ yes ☐ where: ___
10. The results of between-group statistical comparisons are reported for at least one key outcome.	no ☐ yes ☐ where: ___
11. The study provides both point measures and measures of variability for at least one key outcome.	no ☐ yes ☐ where: ___

Assessment of Publication Bias

Assessment of reporting bias was performed using the Egger's weighted regression test [27] and Egger's publication bias graph. In addition, the Duval and Tweedie "trim and fill" method was conducted to explore the potential influence of a publication bias [33].

Sensitivity Analysis

Sensitivity analysis based on the jackknife (leave-one-out) method was conducted to assess the influence of each individual study on the overall results [34]. In addition, sensitivity analyses were performed by using only high-quality studies in the meta-analyses to see if this altered the results.

Data Synthesis

Considering that all studies shared basic methodological aspects (e.g., all were clinical trials with comparison groups) and that clinical studies used participants with similar characteristics (people with LBP), we considered them appropriate for meta-analysis [17]. Stata software (version 14; Stata Corp., College Station, TX, USA) was used to perform the meta-analysis for the primary outcomes. If the data required were not available in a study, it was excluded from the meta-analysis. When the outcome data were presented as figures or plots, WebPlotDigitizer (https://apps.automeris.io/wpd/) was used to digitize the figures in order to extract the relevant data. If a study had more than one reassessment during the study period, the most recent reassessment data were used in the meta-analysis. All studies only included short-term follow-up (less than three months after randomization) [31]; thus, this review evaluated the *short-term* effectiveness of slump stretching on LBP.

The overall quality of the evidence and strength of the recommendations were evaluated using GRADE [35], which was applied for the primary outcomes included in the meta-analysis. The downgrading process was based on the five domains of study limitations, inconsistency, indirectness of evidence, imprecision, and publication bias. The quality of evidence was classified as the following: (1) *high quality*—further research is unlikely to change our confidence in the estimate of effect; the PEDro scale identified no risks of bias, and all domains in the GRADE classification were fulfilled; (2) *moderate quality*—further research is likely to have an important impact on our confidence in the estimate of effect, and one of the domains in the GRADE classification was not fulfilled; (3) *low quality*—further research is likely to have an important impact on our confidence and is likely to change the estimate; two of the domains were not fulfilled in the GRADE classification; and (4) *very low quality*—we are uncertain about the estimate; three of the domains in the GRADE classification were not fulfilled [35].

Results

Identification of Studies

The PRIMSA flow chart (Figure 1) displays the study selection process that was adopted. A total of 524 studies were retrieved from different databases. Nineteen full-text articles were screened for eligibility. One study included asymptomatic participants [36], five studies were review articles [17,19,20,22,23], and one had a pretest–post-test design [37]. Thus, 12 studies met the inclusion criteria and were included in this review. Three studies (25%) compared slump stretching with any other physical therapy intervention (i.e., cognitive exercise [38], short-wave diathermy [39], stabilization exercise [39], postero-anterior mobilization [39], Mulligan's technique [40]). Nine studies (75%) examined the additional benefit of slump stretching combined with another intervention (i.e., advice [41], stretching [42], exercise [8,10,42–47], short-wave diathermy [43], hot pack [47], mobilization [8,10,44,45]). Of the 12 studies included in this systematic review, two (17%) examined three-arm comparisons [39,46].

Overview of Participant Characteristics

The descriptions of the studies are summarized in Table 4. A total of 515 LBP patients were enrolled in these studies. The majority of the trials (seven studies; 58%) enrolled nonradicular LBP patients [8,10,38,42,44,45,47]. Three

Table 4. Studies are listed in a time-ordered manner from most recent to oldest by year of publication

#	Study	Design/Quality	Participant Characteristics	Intervention	Dosage of Intervention	Outcome Measures	Conclusion
1	Ferreira et al. 2016 (Brazil) [41] *Journal of Physiotherapy*	Randomized controlled trial/ high quality, low ROB	60 patients with chronic nerve-related leg pain Experimental group (N = 30; 8 ♂, 22 ♀) Mean age: 43.9 ± 14.5 y BMI: 26.8 ± 4.2 kg/m^2 Comparison group (N = 30; 7 ♂, 23 ♀) Mean age: 40.3 ± 12.9 y BMI: 27.3 ± 4.6 kg/m^2	Experimental group: slump stretching + advice to remain active + lumbar foramen opening mobilizations + home exercise Comparison group: advice to remain active	Slump stretching: 2 sets of 30 repetitions + one additional set of 30 repetitions (combined neck flexion and knee flexion with neck extension and knee extension) Mobilization: grade III, 2 sets of 30 oscillations at 0.5 Hz + one additional set of 30 oscillations if the participant's symptoms did not worsen Home exercise: one sliding (active sliding in slump sitting) and one tensioning technique (active knee extension in supine), one set of 10 repetitions twice a day Frequency: twice weekly for 2 wk for a total of 4 sessions	Leg and back pain (NPRS), disability (ODI), function (PSFS), location of symptoms, global perceived effect *Reassessments were performed at the end of 2nd and 4th weeks*	At 2 weeks, the experimental group did not have greater improvement than the control group in leg pain or disability. At 4 weeks, the experimental group showed greater reduction in leg pain and LBP. The experimental group also improved significantly more in function at 2 weeks and 4 weeks, as well as global perceived effect at 2 weeks and 4 weeks. No significant between-group differences were observed in disability at 4 weeks or location of symptoms.
2	Jaidka and Singh 2016 (India) [39] *Indian Journal of Physiotherapy and Occupational Therapy*	Randomized controlled trial/low quality, high ROB	45 CLBP patients whose age ranged from 20 to 50 y Experimental group (N = 15) Comparison group A (N = 15) Comparison group B (N = 15)	Experimental group: slump stretching + SWD + lumbar stabilization exercises (multifidus and TrA contractions in hook lying and prone positions, pelvic bridging, pelvic tilts) + TENS Comparison group A: SWD + lumbar stabilization exercises (multifidus and TrA contractions in hook lying and prone positions, pelvic bridging, pelvic tilts) + TENS Comparison group B: group A treatment protocols + postero-anterior spinal mobilization	Slump stretching: 30-s hold time, 5 repetitions, 3–4-min total time; the therapist applied overpressure into cervical spine flexion SWD: 27.12 MHz, 15 min Exercise: 2 sets of 10 repetitions, 10-s hold time TENS: 8 Hz, 30 min Mobilization: grade I, + 3 sets of 40-s oscillations to the most painful segment at a rate of 1 to 2 Hz if the participant's symptoms did not worsen + 2 sets of 40-s oscillations to the remaining vertebrae	Pain (VAS), disability (ODI), SLR range *Reassessments were performed at 3rd and 6th treatment sessions*	The postero-anterior spinal mobilization and slump stretching techniques were equally effective ($P > 0.05$) in the treatment of CLBP patients.

(continued)

Table 4. continued

#	Study	Design/Quality	Participant Characteristics	Intervention	Dosage of Intervention	Outcome Measures	Conclusion
3	Kirthika et al. 2016 (India) [42] *International Journal of Physiotherapy and Occupational Therapy*	Randomized controlled trial/low quality, high ROB	30 NRLBP patients whose age ranged from 18 to 60 y Experimental group (N = 15) Comparison group (N = 15)	Experimental group: slump stretching + stretching of both legs + core stabilization exercise protocol (pelvic bridging, single leg abdominal press, double leg abdominal press, segmental rotation and quadruped) + endurance exercise protocol Comparison group: stretching of both legs + core stabilization exercise protocol (pelvic bridging, single leg abdominal press, double leg abdominal press, segmental rotation and quadruped) + endurance exercise protocol	Stretching exercise: 20–30-s hold time, 3–5 repetitions for each leg for a period of 6 wk Core stabilization exercise: 10-s hold time, 10 repetitions for each leg for a period of 6 wk	Pain (NPRS), disability (MODI) *Reassessment was performed at the end of treatment (6 wk)*	Slump stretching combined with conventional physical therapy was more effective than conventional physical therapy alone ($P < 0.001$) in reduction of pain and disability in patients with subacute NRLBP.
4	Ali et al. 2015 (Pakistan) [43] *Rawal Medical Journal*	Randomized controlled trial/low quality, high ROB	40 CRLBP patients Experimental group (N = 22; 4 ♂, 18 ♀) Mean age: 34.3 ± 8.9 y Comparison group (N = 18; 6 ♂, 12 ♀) Mean age: 33.2 ± 7.1 y	Experimental group: slump stretching + lumber stabilization exercise + SWD Comparison group: lumber stabilization exercise + SWD	3 wk	Pain (NPRS), disability (ODI) *Reassessment was performed at the end of treatment (3 wk)*	Slump stretching, along with exercise and SWD, improved pain and function more as compared with exercise and SWD alone ($P < 0.001$) during the management of CRLBP.
5	Mansuri and Shah 2015 (India) [47] *International Archives of Integrated Medicine*	Randomized controlled trial/low quality, high ROB	60 NRLBP patients, aged 20–50 y with positive slump test and negative SLR test	Experimental group: slump stretching + hot pack + isometric exercise Comparison group: hot pack + isometric exercise	Slump stretching: 30-s hold time, 5 repetitions; therapist applied overpressure into cervical spine flexion and knee extension, to the point where the patient's symptoms were reproduced Hot pack: 20 min in prone lying Isometric exercises: isometric flexion exercise in crook lying (10-s hold time, 10 repetitions) + isometric back extension in supine position (10-s hold time, 10 repetitions)	Pain (NPRS), disability (MODI), AKE (goniometer) *Reassessment was performed at the end of 6 treatment sessions*	Addition of slump stretching to exercise protocol in NRLBP patients showed significant improvement in pain, disability, and knee extension range of motion ($P < 0.001$).

(continued)

Table 4. continued

#	Study	Design/Quality	Participant Characteristics	Intervention	Dosage of Intervention	Outcome Measures	Conclusion
6	Karthikeyan et al. 2014 (India) [45] *Indian Journal of Physiotherapy and Occupational Therapy*	Randomized controlled trial/low quality, high ROB	40 NRLBP patients whose age ranged from 20 to 45 y Experimental group (N = 20) Comparison group (N = 20)	Experimental group: slump stretching + mobilization + static spinal exercises Comparison group: mobilization + static spinal exercises	Slump stretching: 30-s hold time, 5 repetitions, 3–4-min total time + self-slump stretching at home without active neck flexion Mobilization: grades III and IV Total treatment time for both groups: 30 min	Pain (NPRS), disability (ODI), patient beliefs (FABQ) *Reassessment was performed at the end of treatment*	Slump stretching was beneficial in the treatment of patients with nonradicular LBP.
7	Patel 2014 (India) [40] *Indian Journal of Physiotherapy and Occupational Therapy*	Randomized clinical trial/low quality, high ROB	50 LBP patients with unilateral limitation of SLR >15° Experimental group (N = 25) Comparison group (N = 25)	Experimental group: slump stretching Comparison group: Mulligan's bent leg raise technique in supine position	Slump stretching: 30-s hold time, 3 repetitions per session Mulligan's technique: 30-s isometric contractions, 3 repetitions for 1 session Frequency: 4 sessions/wk for 4 wk	Pain (VAS), passive SLR (goniometer) *Reassessment was performed at the end of treatment (4 wk)*	After 4 weeks, the Mulligan (comparison) group showed greater but not statistically significant improvement in pain ($P = 0.115$) and ROM of passive SLR ($P = 0.098$) compared with the slump stretching group.
8	Ravinder et al. 2014 (India) [38] *International Journal of Physiotherapy and Research*	Randomized clinical trial/low quality, high ROB	40 NRLBP patients whose age ranged from 18 to 70 y Experimental group (N = 20; 14 ♂, 6 ♀) Comparison group (N = 20; 14 ♂, 6 ♀)	Experimental group: Slump stretching + exercise (bridging, pelvic tilts, quadruped with alternate arm and leg raise and wall squats) Comparison group: cognitive intervention (functional examination of individual problems, feedback and advice) + exercise (bridging, pelvic tilts, quadruped with alternate arm and leg raise and wall squats)	Slump stretching: 30-s hold time, 20-s rest time, 5 repetitions, 3–4-min total time Exercise: 2 sets, 10 repetitions, 5-min rest time Frequency: twice weekly for 3 wk for a total of 6 sessions	Pain (NPRS), disability (ODI), patient beliefs (FABQ), centralization of pain (body diagram) *Reassessment was performed at the end of treatment (3 wk)*	The results indicated that slump stretching was beneficial for improving disability, decreasing pain, and centralization of symptoms compared with treatment of cognitive intervention ($P < 0.001$).

(continued)

Table 4. continued

#	Study	Design/Quality	Participant Characteristics	Intervention	Dosage of Intervention	Outcome Measures	Conclusion
9	Jain et al. 2012 (India) [44] *Indian Journal of Physiotherapy and Occupational Therapy*	Randomized controlled trial/low quality, high ROB	30 patients with subacute NRLBP (11♂, 19♀) Experimental group (N = 15) Mean age: 34.2 ± 5.6 y Symptom duration: 8.0 ± 1.0 wk Comparison group (N = 15) Mean age: 33 ± 6.8 y Symptom duration: 8.2 ±1.1 wk	Experimental group: slump stretching + postero-anterior spinal mobilization + exercises Comparison group: Postero-anterior spinal mobilization + exercises	Slump stretching: 30-s hold time, 5 repetitions + self-slump stretching exercise once daily at home (30-s hold time, 2 repetitions) Mobilization: graded oscillation, 3 sets of 40-s oscillations to the most painful segment at a rate of 1 to 2 Hz + 2 sets of 40-s oscillations to the remaining vertebrae Exercise: core stabilization protocol (in supine, sitting, prone, kneeling, standing, bridging, leg slide, single leg and arm raises, quadruped and segmental rotation positions; 10-s hold time, 10 repetitions) + endurance exercise protocol (trunk extensor exercises consisting of 4 levels; 10-s hold time, 10 repetitions) Frequency: 9 sessions (3 d/wk for 1st wk and 2 d/wk for next 3 wk)	Pain (VAS), disability (MODI) *Reassessments were performed at the end of weeks 1, 2, 3, 4, and 5*	Combination of slump stretching and conventional physical therapy was more effective than conventional physical therapy alone in improving pain in patients with nonradicular subacute LBP. Though there was no significant difference in disability parameter between the groups until 4 weeks ($P \geq 0.078$), the experimental group showed recovery by the 5th week ($P < 0.05$).
10	Malik et al. 2012 (India) [46] *International Journal of Health and Rehabilitation Sciences*	Randomized controlled trial/fair quality, medium ROB	30 LBP patients whose age ranged from 18 to 60 y Experimental group (N = 13) Comparison group A (N = 15) Comparison group B (N = 12)	Experimental group: slump stretching + core stabilization exercise (multifidus and TrA contractions in hook lying and prone positions) Comparison group A: SLR + core stabilization exercise (multifidus and TrA contractions in hook lying and prone positions) Comparison group B: core stabilization exercise (multifidus and TrA contractions in hook lying and prone positions)	Slump stretching: 30-s hold time, 3–5 repetitions, therapist-applied overpressure into cervical spine flexion and knee extension, to the point where the patient's symptoms were reproduced SLR: 30-s hold time; these sequences were repeated several times, through which the amplitude of the technique was increased according to the patient response Frequency: twice weekly for 3 wk	Pain (NPRS), range of passive SLR (inclinometer) *Reassessment was performed at the end of treatment (3 wk)*	Both SLR and slump stretching were equally effective in improving pain in patients with LBP ($P = 0.952$). However, slump stretching was better than SLR stretching in increasing the range of passive SLR ($P = 0.000$).

(continued)

Table 4. continued

#	Study	Design/Quality	Participant Characteristics	Intervention	Dosage of Intervention	Outcome Measures	Conclusion
11	Nagrale et al. 2012 (India) [8] *Journal of Manual and Manipulative Therapy*	Randomized controlled trial/ high quality, low ROB	60 NRLBP patients whose age ranged from 18 to 60 y Experimental group (N = 30; 9 ♂, 21 ♀) Mean age: 38.2 ± 3.7 y Symptom duration: 15.2 ± 2.5 wk Comparison group (N = 30; 12 ♂, 18 ♀) Mean age: 37.7 ± 4.7 y Symptom duration: 14.7 ± 1.7 wk	Experimental group: slump stretching + postero-anterior lumbar spine mobilization + core stabilization exercise Comparison group: postero-anterior lumbar spine mobilization + core stabilization exercise	Slump stretching: 30-s hold time, 5 repetitions + self-slump stretching home at home (30-s hold time, 2 repetitions) Mobilization: grade III or IV, 3 sets of 40-s oscillations to the most painful segment + 2 sets of 40-s oscillations to the remaining vertebrae Core stabilization exercise: 2 sets of 10 repetitions of wall squats, bridges, pelvic tilts, and quadruped arm and leg lifts Frequency: twice weekly for 3 wk for a total of 6 treatment sessions	Pain (NPRS), disability (ODI), patient beliefs (FABQ) *Reassessments were performed at the end of weeks 1, 2, 3, and 6*	The results showed that slump stretching in a clinical and home exercise program, along with lumbar spine mobilization and stabilization exercises, appears to be more beneficial for rate and magnitude of recovery of self-reported disability ($P \leq 0.02$), pain ($P \leq 0.01$), and fear avoidance behavior ($P = 0.00$) compared with treatment without slump stretching.
12	Cleland et al. 2006 (USA) [10] *Manual Therapy*	Randomized controlled trial/ high quality, low ROB	30 NRLBP patients Experimental group (N = 14; 4 ♂, 10 ♀) Mean age: 40.0 ± 12.2 y Comparison group (N = 16; 5 ♂, 11 ♀) Mean age: 39.4 ± 11.3 y	Experimental group: slump stretching + exercise (pelvic tilts, bridging, wall squats, quadruped alternate arms/legs activities) + lumbar mobilization Comparison group: exercise (pelvic tilts, bridging, wall squats, quadruped alternate arms/legs activities) + lumbar mobilization	Slump stretching: 30 s hold time, 5 repetitions, 3–4 min total time Exercise: 2 sets of 10 repetitions of each exercise; patients were instructed to perform the exercises at home once daily Mobilization: grades III & IV Frequency: twice weekly for 3 wk for a total of 6 sessions	Pain (NPRS, disability (ODI), self-report body diagram *Reassessment was performed at the end of treatment (3 wk)*	The experimental group demonstrated significantly greater improvements in disability ($P < 0.01$), pain ($P = 0.001$), and centralization of symptoms ($P = 0.002$) than the control group.

The shaded studies were excluded from the quantitative analyses.

AKE = active knee extension range; BMI = body mass index; CLBP = chronic low back pain; CRLBP = chronic radicular low back pain; FABQ = Fear Avoidance Belief Questionnaire; LBP = low back pain; MODI = Modified Oswestry Disability Index; NPRS = numeric pain rating scale; NRLBP = nonradicular low back pain; ODI = Oswestry Disability Index; PSFS = Patient-Specific Functional Scale; ROB = risk of bias; SLR = straight leg raise; SWD = short-wave diathermy; TENS = transcutaneous electrical nerve stimulation; TrA = transverse abdominal; VAS = visual analog scale.

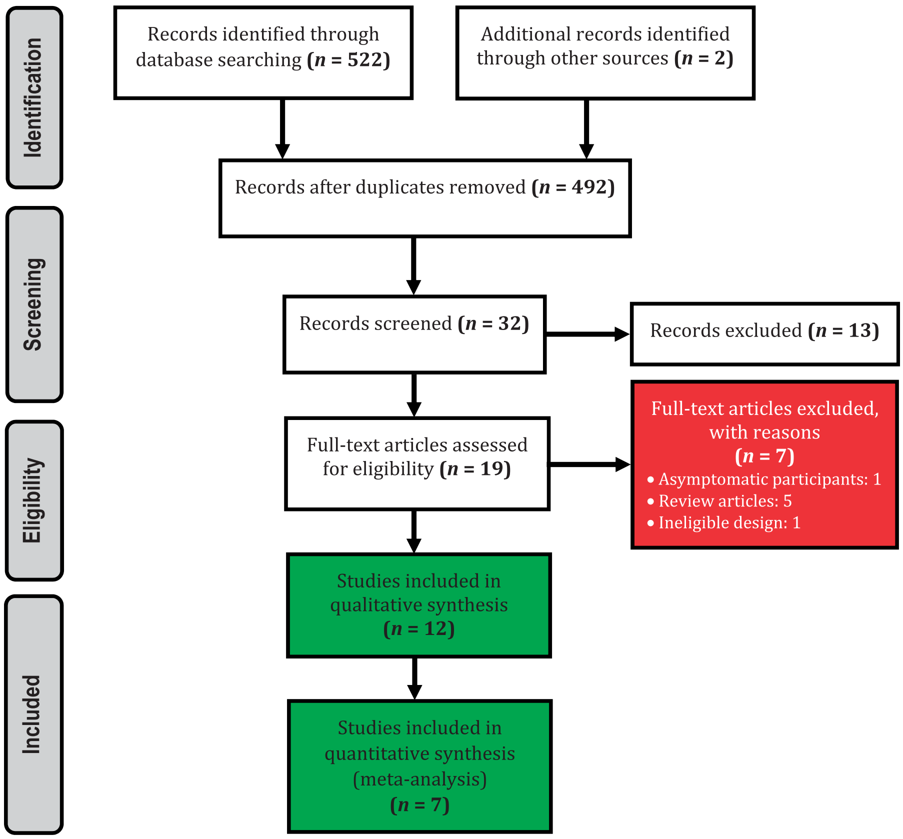


Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram.

studies (25%) recruited chronic LBP patients [39,41,43], and one study (8%) included LBP patients with unilateral limitation of SLR of more than 15° [40]. Malik et al. [46] did not provide detailed information about LBP subclassification. The age of the study populations at baseline ranged from 18 to 70 years. Seven studies (58%) provided little or no information regarding the patient demographic characteristics [38–40,42,45–47]. Sample size calculation was apparent in only two studies (17%) [10,41].

Methodological Considerations and Outcome Measures

Nine of the 12 included studies (75%) have been conducted in India [8,38–40,42,44–47], and the remaining clinical trials were from the United States (8%) [10], Brazil (8%) [41], and Pakistan (8%) (Table 4) [43]. In addition, 10 of the selected studies (83%) were randomized controlled trials [8,10,39,41–47], and the other two (17%) were randomized clinical trials [38,40]. All eligible studies (100%) evaluated pain, whereas 10 (83%) evaluated disability [8,10,38,39,41–45,47]. Four studies (33%) assessed ROM following a period of slump stretching treatment [39,40,46,47]. Three trials (25%) assessed the range of SLR [39,40,46], and one trial (8%) studied active knee extension ROM [47]. The studies used a mean hold time of 30 seconds with three to five repetitions to evaluate the effectiveness of slump stretching. However, Ferreira et al. [41] prescribed 30 repetitions of slump stretching for their participants. Self–slump stretching at home was encouraged in four studies (33%) [8,41,44,45]. The total treatment duration ranged from two weeks to four weeks in most studies (58%) [8,10,38,40,41,44,46].

Quality Assessment and Level of Evidence

The results of the quality assessment and levels of evidence are reported in Table 5 and Figure 2. The level of inter-rater agreement of quality assessment was good ($\kappa = 0.66 \pm 0.23$). Of the 12 trials, three (25%) [8,10,41] were of high quality according to the PEDro scale. One study (8%) [46] was rated as fair quality, and eight (67%) [38–40,42–45,47] were graded as low quality. All studies (100%) had clearly defined eligibility criteria [8,10,38–47]. The criteria that were most frequently not met were allocation concealment, blinding of patients, therapists, and assessors, intention-to-treat analysis, and effect size report. The level of evidence for three studies (25%) was 1b [8,10,41], whereas the remaining clinical trials (nine studies; 75%) had a level of evidence of 2b [38–40,42–47].

Effects of Interventions

Sufficient data were available in only seven studies [8,10,38,41–43,47]; thus, the meta-analysis was conducted on these trials.

Table 5. Levels of evidence and the PEDro scores for all included studies

#	Author	Year	Level of Evidence	Total PEDro Score	1	2	3	4	5	6	7	8	9	10	11
1	Ali et al. [43]	2015	2b	2/10	☺	☺	☹	☹	☹	☹	☹	☺	☹	☹	☹
2	Cleland et al. [10]	2006	1b	8/10*	☺	☺	☺	☺	☹	☹	☺	☺	☺	☺	☺
3	Ferreira et al. [41]	2016	1b	7/10*	☺	☺	☺	☺	☹	☹	☹	☺	☺	☺	☺
4	Jaidka and Singh [39]	2016	2b	2/10	☺	☹	☹	☹	☹	☹	☹	☺	☹	☺	☹
5	Jain et al. [44]	2012	2b	3/10	☺	☺	☹	☺	☹	☹	☹	☹	☹	☺	☹
6	Karthikeyan et al. [45]	2014	2b	1/10	☺	☹	☹	☹	☹	☹	☹	☺	☹	☹	☹
7	Kirthika et al. [42]	2016	2b	3/10	☺	☹	☹	☺	☹	☹	☹	☺	☹	☺	☹
8	Malik et al. [46]	2012	2b	4/10	☺	☺	☹	☺	☹	☹	☹	☺	☹	☺	☹
9	Mansuri and Shah [47]	2015	2b	3/10	☺	☹	☹	☺	☹	☹	☹	☺	☹	☺	☹
10	Nagrale et al. [8]	2012	1b	8/10*	☺	☺	☺	☺	☹	☹	☺	☺	☺	☺	☺
11	Patel [40]	2014	2b	3/10	☺	☺	☹	☹	☹	☹	☹	☺	☹	☺	☹
12	Ravinder et al. [38]	2014	2b	3/10	☺	☺	☹	☹	☹	☹	☹	☺	☹	☺	☹

*Indicates high-quality studies.

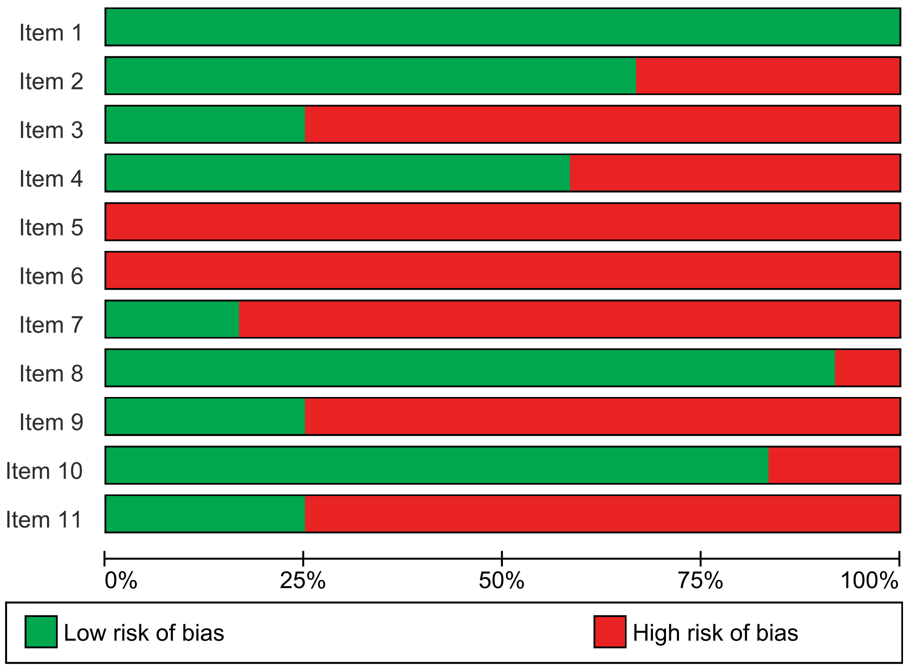


Figure 2. Risk of bias graph: review of authors' judgments about each risk of bias item, presented as percentages across all included studies.

Effects on Back Pain Intensity

All trials included in the meta-analysis (N = 7) reported pain outcome at baseline and at short-term follow-up [8,10,38,41–43,47]. Pooled SMD showed large significant between-group differences on mean change scores for back pain intensity post-treatment (SMD = –2.15, 95% CI = –3.35 to –0.95) (Figure 3). Ali et al. [43] showed that the addition of slump stretching to conventional physical therapy (Table 4) significantly improved pain scores in chronic radicular LBP patients (SMD = –0.93, 95% CI = –1.58 to –0.27). In a randomized clinical trial conducted by Cleland et al. [10], it was shown that slump stretching improved short-term pain and centralization of symptoms in individuals with nonradicular LBP (SMD = –3.09, 95% CI = –4.17 to –2.01).

Ferreira et al. [41] concluded that adding slump stretching to advice to remain active improved LBP at four weeks (SMD = –0.41, 95% CI = –0.92 to 0.10). However, one high-quality study [8] examined slump stretching coupled with lumbar spine mobilization and stabilization exercises compared with lumbar spine mobilization and stabilization exercises alone. The SMD for Nagrale et al. [8] indicated that slump stretching produced a greater reduction in pain as compared with control treatment at six-week follow-up (SMD = –2.52, 95% CI = –3.21 to –1.84). Other low-quality clinical trials [38,42,47] have also shown the superior effects of slump

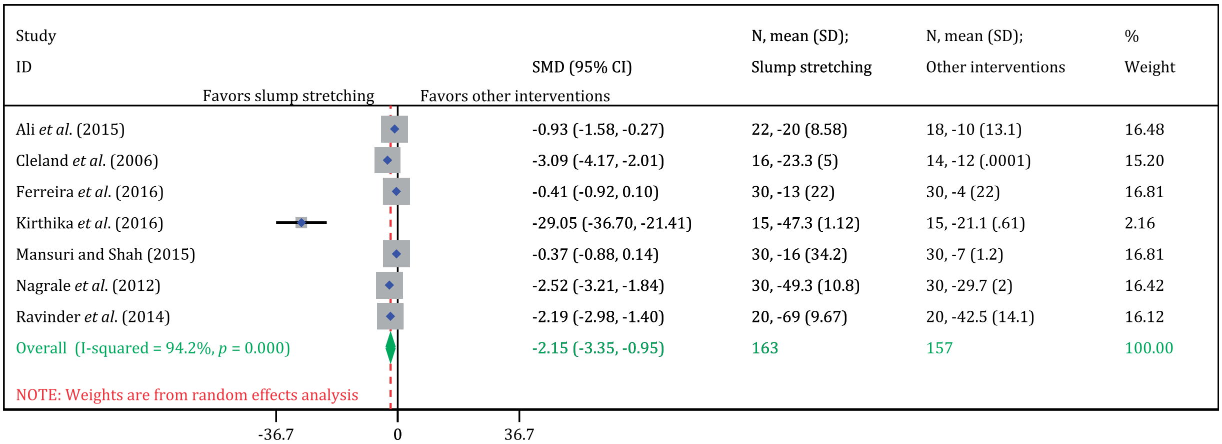


Figure 3. Forest plot of comparison: slump stretching vs all other physical therapies, outcome "pain."

stretching combined with conventional treatment (exercise [38,42,47] and hot pack [47]) on pain reduction in patients with LBP (SMDs = –29.05 to –0.37, 95% CI = –36.70 to 0.14).

The result of the meta-analysis indicated that the effect of slump stretching on pain reduction was clinically important because the effect size was large (SMD = –2.15). Statistical testing indicated that there was considerable heterogeneity in pain among the eligible studies ($\chi^2 = 103.12$, $P = 0.00$, $I^2 = 94.2\%$).

Effects on Disability

All trials included in the meta-analysis (N = 7) measured disability at baseline and at short-term follow-up [8,10,38,41–43,47]. Pooled SMD showed large significant between-group differences on mean change scores for disability post-treatment (SMD = –8.03, 95% CI = –11.59 to –4.47) (Figure 4). Ali et al. [43] compared slump stretching combined with exercise and short-wave diathermy with exercise and short-wave diathermy alone. Their study indicated that adding slump stretching to conventional treatment improved disability (SMD = –12.95, 95% CI = –15.93 to –9.97) [43]. Cleland et al. [10] found that six sessions of slump stretching combined with lumbar spine mobilization and exercise was beneficial for improving short-term disability (SMD = –11.12, 95% CI = –14.13 to –8.12). The effectiveness of slump stretching has been confirmed in other studies (Figure 4 and Table 4) [38,41,42,47]. Furthermore, the SMD calculated for Nagrale et al. [8] showed that slump stretching combined with conventional treatment (i.e., lumbar mobilization and exercise) produced significantly better results than conventional treatment at six-week follow-up (SMD = –9.98, 95% CI = –11.87 to –8.10).

The result of the meta-analysis indicated that the slump stretching level of decrease in disability in patients with LBP was clinically important (SMD = –8.03). Statistical testing for heterogeneity indicated that there was considerable heterogeneity in disability among the eligible studies ($\chi^2 = 269.67$, $P = 0.00$, $I^2 = 97.8\%$).

Effects on ROM

Meta-analysis was not performed for the secondary outcome (i.e., ROM) because there were no appropriate data available in the eligible studies; therefore, qualitative synthesis of the results was conducted. Jaidka and Singh [39] evaluated the effect of slump stretching combined with conventional treatment and lumbar mobilization combined with conventional treatment on SLR ROM. They concluded that both postero-anterior mobilization and slump stretching techniques were equally effective in improving SLR ROM in patients with chronic LBP (mean difference [MD] = 61.78° and 66.44°, respectively) [39]. Malik et al. [46] reported that slump stretching was more effective than SLR stretching in increasing passive SLR ROM (Table 4). Moreover, a clinical trial conducted by Patel [40] showed that there was no statistically significant difference between Mulligan's bent leg raise technique and slump stretching in improving passive SLR ROM (MD = 17.40° and 15.28°, respectively). Mansuri and Shah [47] mentioned that adding slump stretching to conventional physical therapy for patients with nonradicular LBP increased active knee extension ROM significantly compared with conventional physical therapy alone (MD = –4.90° and –2.16°, respectively).

Sensitivity Analysis

The inclusion of sensitivity analysis using only high-quality studies (PEDro score ≥ 6) in the meta-analyses on pain outcome did not change the results. Pooled SMD demonstrated a large significant between-group difference on mean change scores for pain intensity post-treatment (SMD = –1.97, 95% CI = –3.69 to –0.25) (Figure 5). However, sensitivity analysis on disability outcome changed the results. Pooled SMD demonstrated a large but nonsignificant between-group difference on mean change scores for disability post-treatment (SMD = –7.13, 95% CI = –14.92 to 0.67) (Figure 6). Changes in the results highlight the influence of low-quality studies (PEDro score ≤ 3) on the pooled SMD.

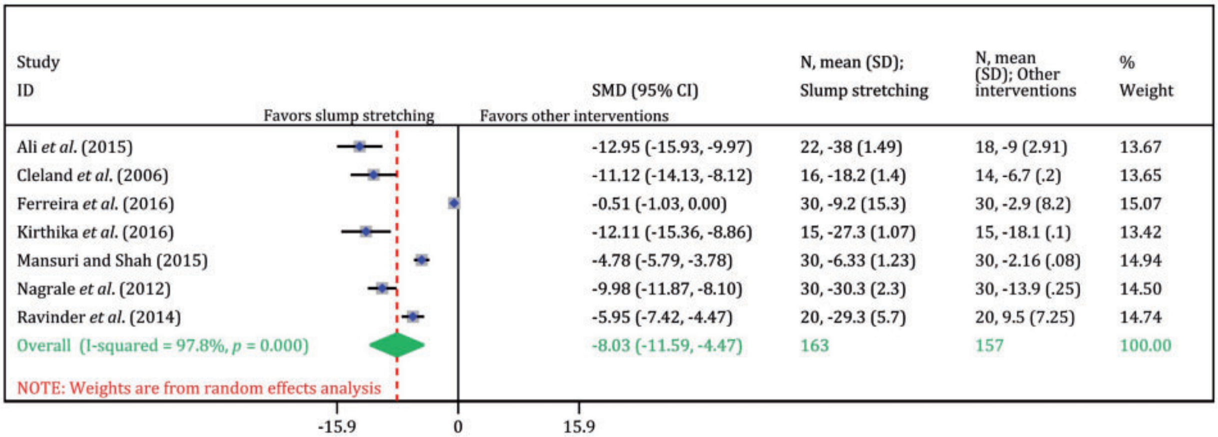


Figure 4. Forest plot of comparison: slump stretching vs all other physical therapies, outcome "disability."

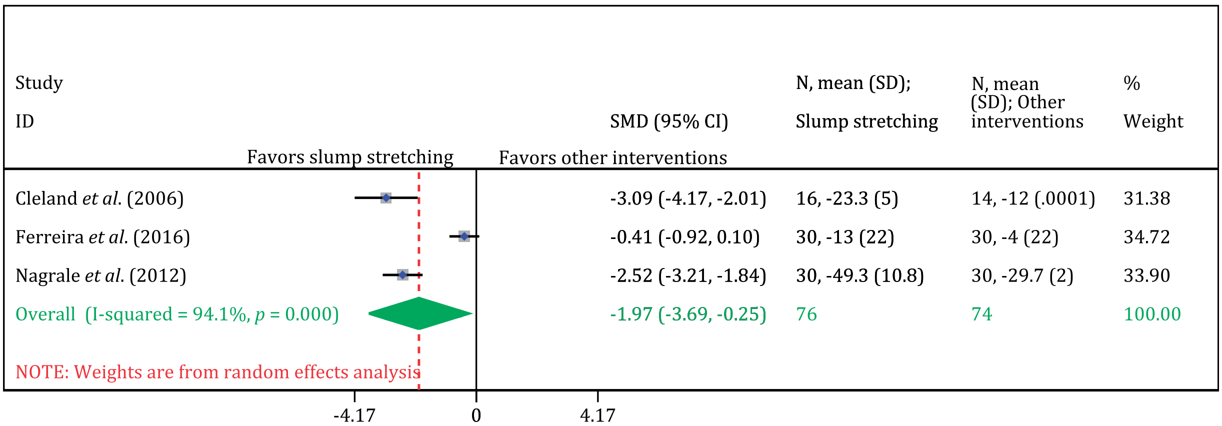


Figure 5. Forest plot of sensitivity analysis for high-quality studies: slump stretching vs all other physical therapies, outcome "pain."

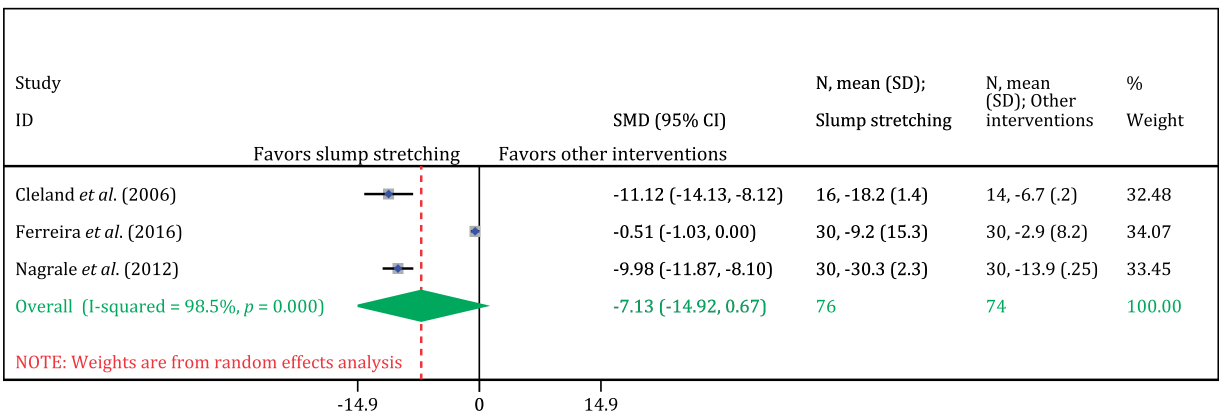


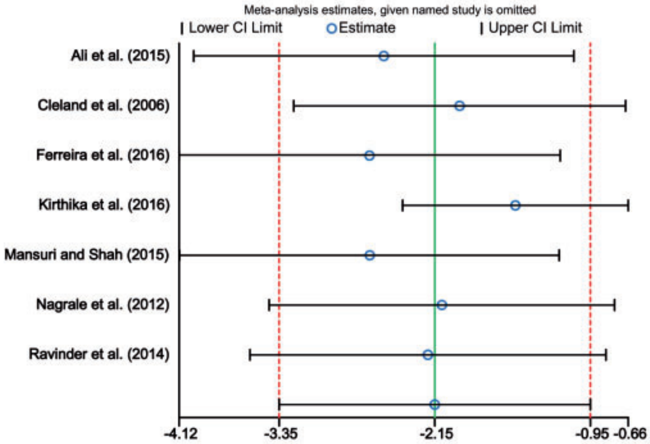
Figure 6. Forest plot of sensitivity analysis for high-quality studies: slump stretching vs all other physical therapies, outcome "disability."

The impact of individual studies on the overall meta-analysis estimates was assessed. The results of leave-one-out sensitivity analysis revealed that the included studies influenced the pooled SMDs of pain outcome from –2.65 (95% CI = –4.12 to –1.18) after excluding the study of Ferreira et al. [41] to –1.53 (95% CI = –2.40 to –0.66) after excluding the study of Kirthika et al. (Figure 7A) [42]. For the outcome disability, sensitivity analysis demonstrated that the eligible studies also had a significant influence on the pooled SMDs, ranging from

A

Influence analysis of each study on the pooled estimate of "**pain**" outcome.

Study omitted	SMD	Lower limit	Upper limit
Ali *et al.* (2015)	-2.5422544	-4.0086842	-1.0758246
Cleland *et al.* (2006)	-1.957432	-3.2374096	-0.67745429
Ferreira *et al.* (2016)	-2.6517744	-4.1220779	-1.181471
Kirthika *et al.* (2016)	-1.5271977	-2.3978651	-0.65653032
Mansuri and Shah (2015)	-2.6501737	-4.1114149	-1.1889323
Nagrale *et al.* (2012)	-2.0945189	-3.4273736	-0.76166403
Ravinder *et al.* (2014)	-2.2015212	-3.5742092	-0.82883304
Combined	**-2.1491368**	**-3.3504**	**-0.94787358**



B

Influence analysis of each study on the pooled estimate of "**disability**" outcome.

Study omitted	SMD	Lower limit	Upper limit
Ali *et al.* (2015)	-7.2308688	-10.824086	-3.637651
Cleland *et al.* (2006)	-7.5306916	-11.240314	-3.8210697
Ferreira *et al.* (2016)	-9.2530937	-12.022949	-6.4832397
Kirthika *et al.* (2016)	-7.3866348	-11.063334	-3.7099345
Mansuri and Shah (2015)	-8.6636295	-13.506051	-3.821208
Nagrale *et al.* (2012)	-7.6768379	-11.324591	-4.0290847
Ravinder *et al.* (2014)	-8.4170103	-12.568681	-4.2653394
Combined	**-8.0308504**	**-11.58818**	**-4.4735217**

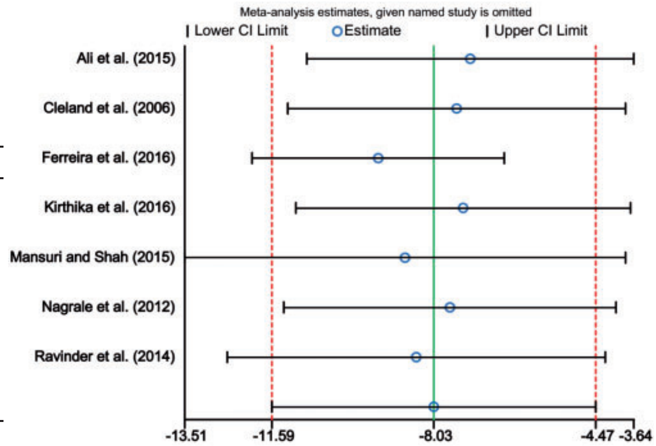


Figure 7. Influence analyses of each individual study on the pooled estimates of the primary outcomes: (A) pain; (B) disability. The left, middle, and right vertical lines are indicators for the minimum, mean, and maximum values of total effect size, respectively.

–9.25 (95% CI = –12.02 to –6.48) after excluding the study of Ferreira et al. [41] to –7.23 (95% CI = –10.82 to –3.64) after excluding the study of Ali et al. [43] (Figure 7B).

Assessment of Publication Bias

The presence of publication bias for pain outcome was confirmed using Egger's linear regression (intercept = –8.68, standard error = 1.57, 95% CI = –12.73 to –4.63, $P = 0.003$) and Egger's graph (Figure 8A). Egger's linear regression (intercept = –10.01, standard error = 1.25, 95% CI = –13.23 to –6.80, $P = 0.000$) and Egger's graph (Figure 8B) showed that there is significant publication bias in the meta-analysis for disability outcome. The application of the trim-and-fill method did not identify a missing study and, thus, left the pooled estimates unchanged. No funnel plot was performed as the number of trials included for each comparison was limited (<10) [27].

Quality of Evidence

The quality of evidence for the outcome measures was assessed using the GRADE approach (Table 6A). For the outcome pain, there was very low-quality evidence (downgraded due to study limitations, inconsistency, imprecision, and publication bias, and upgraded due to large effect size) that slump stretching could improve pain in patients with LBP at short-term follow-up. For the outcome disability, there was very low-quality evidence (downgraded due to study limitations, inconsistency, imprecision, and publication bias, and upgraded due to large effect size) that slump stretching could improve disability in patients with LBP at short-term follow-up.

The quality of evidence was also examined when only high-quality studies were included (Table 6B). The results showed that there was a moderate grade of evidence that slump stretching could reduce pain in LBP patients in the short term. In addition, it has been shown that there was a moderate grade of evidence (downgraded due to inconsistency and imprecision, and upgraded due to large effect size) that slump stretching could improve disability in LBP patients at short-term follow-up.

Discussion

The present study systematically reviewed and performed a meta-analysis regarding the effectiveness of slump

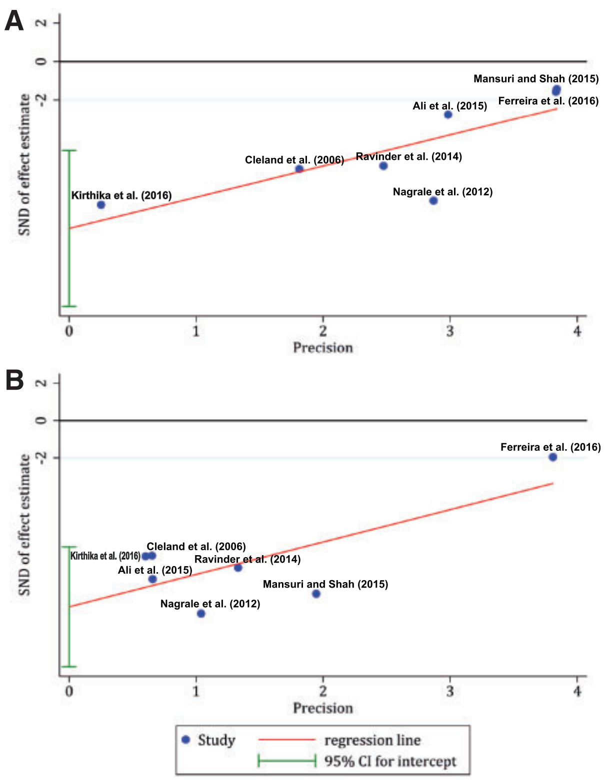


Figure 8. Egger's graphs show that there is a significant publication bias in the meta-analysis for the primary outcomes: (A) pain; (B) disability.

stretching in people with LBP. There were two main findings of this review. Evidence from the pooled effect sizes suggests that slump stretching, either used alone or in combination with other physical therapy interventions, successfully decreased pain level and disability and increased ROM in patients with LBP. In addition, there was significant heterogeneity among the included studies for the primary outcomes.

There is moderate evidence among high-quality studies that slump stretching improves pain in LBP patients. The overall effect size was large, favoring the use of slump stretching to decrease pain in people with LBP. The effect size calculated for each individual trial also supports the positive effects from the application of slump stretching. The benefits from the use of slump stretching were seen in combination with other physical therapy interventions (e.g., exercise, mobilization) or using slump stretching alone and were always superior to control interventions.

Our findings are in accordance with those of Neto et al. [17], Basson et al. [18], Ellis and Hing [19], and Su and Lim [20]. In a recent systematic review and meta-analysis conducted by Neto et al. [17], the effects of lower-body-quadrant neural mobilization were assessed in LBP patients. The results of the present review showed that neural mobilization has large effects on pain in patients with LBP [17]. Basson et al. [18] reported the benefits of neural mobilization for LBP. Ellis and Hing [19] investigated the efficacy of neural mobilization and reported that eight out of 11 clinical trials included showed positive therapeutic effects on pain. Su and Lim [20] demonstrated that neural mobilization provides superior pain relief (SMD = –0.77, 95% CI = –1.11 to –0.42, $P < 0.0001$) for individuals with nerve-related chronic musculoskeletal disorders compared with minimal intervention.

To date, the physiological mechanisms of neural mobilization (slump stretching) on pain relief are poorly understood [17,20], and further studies are required to understand the details of neural mobilization mechanisms. Previous studies have reported immediate positive effects of neural mobilization on pain due to the increased pressure pain threshold [51] and C-fiber-mediated hypoalgesia [52]. In addition, passive neural mobilization can induce dispersion of intraneural fluid and decrease the effects of compression from surrounding fascial restrictions [53].

Neurodynamic mobilization techniques are often used clinically to restore nerve mobility [54,55]. It has been demonstrated that these techniques increase excursion by flossing the nerve [56]. Furthermore, studies have found that neural mobilization techniques reduce fibrosis and adhesion between the neural tissues and surrounding tissues, resulting in improved intrafascicular gliding [53]. Millesi et al. [57] explained transverse contraction of nerve tissue upon the lengthening or stretching of the nerve tissue. They reported that transverse contraction from repetitive elongation/relaxation loading may change intrafascicular pressure. Gilbert et al. [58] hypothesized that this change in intrafascicular pressure leads to pumping or flushing of the intraneural fluid with repetitive elongation/relaxation phases. The pumping effect is thought to displace the intraneural fluid, facilitate the axoplasmatic flow, and minimize the deposition of sensitizing chemicals, which may result in pain relief and improved function [17,53,58].

Neural mobilization techniques can also improve the viscoelastic properties of the nerve, promote motor reinnervation, increase the number of regenerated axons, and decrease the expression of glial proteins linked to degeneration and pain [23,47,59]. The gate control theory of pain proposes that nonaggressive movement may reduce pain [23]. It is expected that neural mobilization techniques can reduce the intensity of pain through nervi nervorum—the innervation of the nerve [23]. From a therapeutic perspective, based on the SMD of each study included, it appears that patients with nonradicular LBP may benefit more from slump stretching than from other types of LBP.

Slump stretching includes lumbar flexion, which can unload the facet joints and increase central canal and neuroforaminal dimension. Therefore, the pain intensity can be reduced, especially in patients with facet syndrome and lumbar spinal stenosis.

Table 6. Grades of Recommendation, Assessment, Development and Evaluation quality of evidence for the primary outcomes

Outcome	Study Limitations	Inconsistency	Indirectness	Imprecision	Publication Bias	Effect Size	GRADE Quality	Direction of Recommendation
A) 7 studies were included								
Pain (SMD = −2.15, 95% CI = −3.35 to −0.95, I^2 = 94.2%)	−1*	−1†	0	−1‡	−1§	+1¶	⊕⊖⊖⊖ (very low)	For
Disability (SMD = −8.03, 95% CI = −11.59 to −4.47, I^2 = 97.8%)	−1*	−1†	0	−1‡	−1§	+1¶	⊕⊖⊖⊖ (very low)	For
B) 3 high-quality studies were included								
Pain (SMD = −1.97, 95% CI = −3.69 to −0.25, I^2 = 94.1%)	0	−1†	0	−1‡	0	+1¶	⊕⊕⊕⊖ (moderate)	For
Disability (SMD = −7.13, 95% CI = −14.92 to 0.67, I^2 = 98.5%)	0	−1†	0	−1‡	0	+1¶	⊕⊕⊕⊖ (moderate)	For

The symbols ⊕⊕⊖⊖ indicate how many of the items were fulfilled (for each ⊕, one item was fulfilled and corresponds to the different levels of evidence).
CI = confidence interval; GRADE = Grades of Recommendation, Assessment, Development and Evaluation; SMD = standardized mean difference.
*Downgraded one level as the majority of trials scored ≤ 6 on the PEDro scale [48].
†Downgraded one level as the I^2 value was >50% [27].
‡Downgraded one level as the total number of participants was <400 [49].
§Downgraded one level due to suspected publication bias [50].
¶Upgraded one level due to large effect size [48].

Our findings reveal moderate evidence across these high-quality studies that slump stretching improves disability in the short term in LBP patients. The superior effect of slump stretching compared with other physical therapy interventions was not significant when only high-quality studies were included. However, the overall effect size was large, favoring the use of slump stretching to decrease disability in patients with LBP. It should be noted that when other studies were also included, slump stretching produced significantly better results for disability outcome. This difference may be due to the influence of low-quality studies on the pooled estimates. All low-quality trials showed statistically significant results in favor of the use of slump stretching for treating LBP patients. Malik et al. [46] suggested that slump stretching can affect posterior myofascial chain flexibility, thus increasing the lumbar and tibio-tarsal joint angles and finger-floor distance, which could be a possible mechanism in the greater improvement of range.

The second main finding is that considerable heterogeneity was observed across the studies for the primary outcomes. Furthermore, when the low-quality studies were removed, the considerable heterogeneity did not change. Possible explanations for this considerable heterogeneity may be differences in the studies regarding control intervention, number of cases and controls, patient baseline characteristics (LBP type), and duration and dosage of treatment.

To investigate the presence of publication bias in our systematic review, two Egger's graphs were generated. As shown in Figure 8, significant publication bias was observed because the 95% CIs of the intercept did not include the null point. Possible explanations for this could be the quality of the studies included, nonpublished trials with negative results, studies showing no difference in results, those with small sample sizes, and the number of studies in each separate meta-analysis.

There are some limitations to our study that should be mentioned. The results of the studies included in this review refer to short-term change after intervention. Hence, it is not possible to draw conclusions about the efficacy of slump stretching at medium- or long-term follow-up. Moreover, a limited number of studies was available (seven in each separate meta-analysis) to investigate the effectiveness of slump stretching on LBP. This limits the conclusions that can be derived from the analysis. The majority of studies selected did not perform power analysis to determine the appropriate sample size. Therefore, the external validity of the findings is limited. The studies included also presented several methodological limitations. The most frequent limitations were related to nonblinding characteristics of studies, random allocation, and intention-to-treat analysis. Finally, database searching was limited to English-language papers, which may have introduced a publication bias and excluded other relevant papers.

Future clinical trials should consider the methodological limitations found in the studies included in this review in order to improve their quality. In addition, future studies that include the appropriate number of patients should investigate long-term follow-up of LBP patients treated with slump stretching. Neto et al. [17] encouraged further research underlying the physiological effects of neurodynamic mobilization techniques (e.g., slump stretching) beyond the clinical effects. This would provide valuable information for the rehabilitation of neuropathy and neuromuscular disorders [17].

Conclusions

Based on the studies included in this review, it can be concluded that there was very low quality of evidence that slump stretching has a positive effect on pain and disability in patients with LBP. When only high-quality studies were considered, the results for disability and the quality of evidence for pain and disability changed. The results showed that the effect of slump stretching on disability improvement compared with other interventions was not significant. Furthermore, a meta-analysis including only the high-quality research indicated that slump stretching has a significant effect on pain alleviation. Although the effect sizes (pooled SMDs) of the primary outcomes were large, the quality of evidence for pain and disability was moderate.

In the present study, statistical heterogeneity analysis demonstrated that there was considerable heterogeneity among the included studies for the primary outcomes (Q-statistic at $P < 0.05$ and $I^2 > 75\%$ for both primary outcomes). Due to the lack of adequate data on ROM, meta-analysis was not possible. However, a qualitative synthesis of evidence suggests that slump stretching can effectively improve SLR and active knee extension ROM in the LBP population. Further high-quality research regarding the long-term effects of slump stretching vs validated control intervention in a clinical setting is recommended.

References

1. Cyriax J. Perineuritis. Br Med J 1942;1 (4244):578–80.
2. Kenneally M, Rubenach H, Elvey R. The upper limb tension test: The SLR test of the arm. In: Grant R, ed. Physical Therapy of the Cervical and Thoracic Spine, Clinics in Physical Therapy. Edinburgh: Churchill Livingstone;1988:167–82.
3. Maitland GD. The slump test: Examination and treatment. Aust J Physiother 1985;31(6):215–9.
4. Davis DS, Anderson IB, Carson MG, Elkins CL, Stuckey LB. Upper limb neural tension and seated slump tests: The false positive rate among healthy young adults without cervical or lumbar symptoms. J Man Manip Ther 2008;16(3):136–41.
5. Sizer PS, Phelps V, Dedrick G, Matthijs O. Differential diagnosis and management of spinal nerve root-related pain. Pain Pract 2002;2(2):98–121.
6. Majlesi J, Togay H, Ünalan H, Toprak S. The sensitivity and specificity of the slump and the straight leg raising tests in patients with lumbar disc herniation. J Clin Rheumatol 2008;14(2):87–91.
7. Coppieters MW, Kurz K, Mortensen TE, et al. The impact of neurodynamic testing on the perception of experimentally induced muscle pain. Man Ther 2005; 10(1):52–60.
8. Nagrale AV, Patil SP, Gandhi RA, Learman K. Effect of slump stretching versus lumbar mobilization with exercise in subjects with non-radicular low back pain: A randomized clinical trial. J Man Manip Ther 2012; 20(1):35–42.
9. Maitland G, Hengeveld E, Banks K, English K. Maitland's Vertebral Manipulation. 6th ed. Oxford: Butterworth-Heinemann; 2001.
10. Cleland JA, Childs JD, Palmer JA, Eberhart S. Slump stretching in the management of non-radicular low back pain: A pilot clinical trial. Man Ther 2006;11 (4):279–86.
11. Nee RJ, Vicenzino B, Jull GA, Cleland JA, Coppieters MW. Neural tissue management provides immediate clinically relevant benefits without harmful effects for patients with nerve-related neck and arm pain: A randomised trial. J Physiother 2012;58(1):23–31.
12. Schäfer A, Hall T, Müller G, Briffa K. Outcomes differ between subgroups of patients with low back and leg pain following neural manual therapy: A prospective cohort study. Eur Spine J 2011;20(3):482–90.
13. Cowell I, Phillips D. Effectiveness of manipulative physiotherapy for the treatment of a neurogenic cervicobrachial pain syndrome: A single case study–experimental design. Man Ther 2002;7(1):31–8.
14. Kobayashi S, Yoshizawa H, Hachiya Y, Ukai T, Morita T. Vasogenic edema induced by compression injury to the spinal nerve root. Distribution of intravenously injected protein tracers and gadolinium-enhanced magnetic resonance imaging. Spine 1993; 18(11):1410–24.
15. Turl SE, George KP. Adverse neural tension: A factor in repetitive hamstring strain? J Orthop Sports Phys Ther 1998;27(1):16–21.
16. Shacklock M, Shacklock MO, eds. Moving in on pain. Chastwood, Australia: Buttersworth Heinemann; 1995:123–31.
17. Neto T, Freitas SR, Marques M, et al. Effects of lower body quadrant neural mobilization in healthy and low back pain populations: A systematic review and meta-analysis. Musculoskelet Sci Pract 2017;27:14–22.
18. Basson A, Olivier B, Ellis R, et al. The effectiveness of neural mobilization for neuromusculoskeletal conditions: A systematic review and meta-analysis. J Orthop Sports Phys Ther 2017;47(9):593–615.
19. Ellis RF, Hing WA. Neural mobilization: A systematic review of randomized controlled trials with an analysis of therapeutic efficacy. J Man Manip Ther 2008;16(1):8–22.
20. Su Y, Lim ECW. Does evidence support the use of neural tissue management to reduce pain and disability in nerve-related chronic musculoskeletal pain? Clin J Pain 2016;32(11):991–1004.

21. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA statement. PLoS Med 2009;6(7):e1000097.
22. Efstathiou MA, Stefanakis M, Savva C, Giakas G. Effectiveness of neural mobilization in patients with spinal radiculopathy: A critical review. J Bodyw Mov Ther 2015;19(2):205–12.
23. Santana H, Fernandes de Oliveira I, Medrado A, Nunes SK. Neurodynamic mobilization and peripheral nerve regeneration: A narrative review. Int J Neurorehabil 2015;2(2):1–7.
24. Hoy D, March L, Brooks P, et al. The global burden of low back pain: Estimates from the Global Burden of Disease 2010 study. Ann Rheum Dis 2014;73 (6):968–74.
25. Pourahmadi MR, Mohsenifar H, Dariush M, Aftabi A, Amiri A. Effectiveness of mobilization with movement (Mulligan concept techniques) on low back pain: A systematic review. Clin Rehabil 2018;32 (10):1289–98.
26. Verhagen AP, de Vet HC, de Bie RA, et al. The Delphi list: A criteria list for quality assessment of randomized clinical trials for conducting systematic reviews developed by Delphi consensus. J Clin Epidemiol 1998;51(12):1235–41.
27. Pourahmadi MR, Taghipour M, Ebrahimi Takamjani I, et al. Motor control exercise for symptomatic lumbar disc herniation: Protocol for a systematic review and meta-analysis. BMJ Open 2016;6(9):1–10.
28. Altman DG. Practical Statistics for Medical Research. London: Chapman & Hall; 1991.
29. Deeks J, Higgins J, Altman D. Chapter 9: Analysing data and undertaking meta-analysis. In: Higgins J, Green S, eds. Handbook for Systematic Reviews. West Sussex: Wiley-Blackwell; 2011:243–96.
30. Rubinstein SM, Terwee CB, Assendelft WJ, de Boer MR, van Tulder MW. Spinal manipulative therapy for acute low back pain: An update of the cochrane review. Spine 2013;38(3):E158–77.
31. Saragiotto BT, Maher CG, Yamato TP, et al. Motor control exercise for chronic non-specific low-back pain. Cochrane Database Syst Rev 2016;1: CD012004.
32. Higgins JP, Green S. Cochrane Handbook for Systematic Reviews of Interventions. New York: John Wiley & Sons; 2011.
33. Duval S, Tweedie R. Trim and fill: A simple funnel–plot–based method of testing and adjusting for publication bias in meta-analysis. Biometrics 2000;56 (2):455–63.
34. Patsopoulos NA, Evangelou E, Ioannidis JP. Sensitivity of between-study heterogeneity in meta-analysis: Proposed metrics and empirical evaluation. Int J Epidemiol 2008;37(5):1148–57.
35. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: An emerging consensus on rating quality of evidence and strength of recommendations. BMJ 2008;336 (7650):924–6.
36. Shacklock M, Yee B, Van Hoof T, et al. Slump test: Effect of contralateral knee extension on response sensations in asymptomatic subjects and cadaver study. Spine 2016;41(4):E205–E10.
37. Karthikeyan T, Ramana R. Effect of slump stretching for the management of non radicular lower back pain among anxiety neurosis. Indian J Phys Ther 2015;2 (2):61–5.
38. Ravinder Y, Ashok A, Vandana Y. Comparison between slump stretching along with exercises and cognitive intervention with exercises in the management of non-radicular low back pain. Int J Physiother Res 2014;2(2):429–34.
39. Jaidka NK, Singh A. Comparison between postero-anterior spinal mobilization and slump stretching in patients with chronic low back pain. Indian J Physiother Occup Ther 2016;10(2):20–5.
40. Patel G. To compare the effectiveness of mulligan bent leg raising and slump stretching in patient with low back pain. Indian J Physiother Occup Ther 2014; 8(3):24–8.
41. Ferreira G, Stieven F, Araujo F, et al. Neurodynamic treatment did not improve pain and disability at two weeks in patients with chronic nerve-related leg pain: A randomised trial. J Physiother 2016;62(4):197–202.
42. Kirthika S, Rajalaxmi V, Sudhakar S, Bhuvaneshwaran T, Thaslim KF. Effect of combining slump stretching with conventional physiotherapy in the treatment of subacute non-radicular low back pain TJPRC. Int J Physiother Occup Ther 2016;2 (2):9–16.
43. Ali M, Ur Rehman SS, Ahmad S, Farooq MN. Effectiveness of slump neural mobilization technique for the management of chronic radicular low back pain. Rawal Med J 2015;40(1):41–3.
44. Jain R, Hameed UA, Tuteja R. Effectiveness of slump stretching in comparison to conventional physiotherapy in treatment of subacute non-radicular low back pain. Indian J Physiother Occup Ther 2012;6(1): 123–26.
45. Karthikeyan JK, Kiran P. Effect of slump stretching with static spinal exercise for the management of non radicular low back pain among non active sports persons. Indian J Physiother Occup Ther 2014;8(4): 175–79.
46. Malik N, Kataria C, Sachdev NB. Comparative effectiveness of straight leg raise and slump stretching in subjects with low back pain with adverse neural tension. Int J Health Rehabil Sci 2012;1(1):2–10.
47. Mansuri F, Shah N. Effect of slump stretching on pain and disability in non-radicular low back pain. Int Arch Integr Med 2015;2(5):18–25.
48. Lewis M, Peiris CL, Shields N. Long-term home and community-based exercise programs improve function in community-dwelling older people with

cognitive impairment: A systematic review. J Physiother 2017;63(1):23–9.
49. Scholten-Peeters GG, Thoomes E, Konings S, et al. Is manipulative therapy more effective than sham manipulation in adults?: A systematic review and meta-analysis. Chiropr Man Therap 2013;21(1):1–19.
50. Rattehalli RD, Zhao S, Li BG, et al. Risperidone versus placebo for schizophrenia. Cochrane Database Syst Rev 2016;12:CD006918.
51. Silva LI, Rocha BP, Antunes JS, et al. Evaluation of the pressure pain threshold after neural mobilization in individuals with sciatica. Eur J Physiother 2013;15 (3):146–50.
52. Beneciuk JM, Bishop MD, George SZ. Effects of upper extremity neural mobilization on thermal pain sensitivity: A sham-controlled study in asymptomatic participants. J Orthop Sports Phys Ther 2009;39 (6):428–38.
53. Brown CL, Gilbert KK, Brismee JM, et al. The effects of neurodynamic mobilization on fluid dispersion within the tibial nerve at the ankle: An unembalmed cadaveric study. J Man Manip Ther 2011;19(1):26–34.
54. Martinez JA Jr. Neuromobilization vs. Conventional Physical Therapy for Lumbar Radiculopathy. Albuquerque, NM: University of New Mexico; 2018.
55. Cha H-K, Cho H-S, Choi J-D. Effects of the nerve mobilization technique on lower limb function in patients with poststroke hemiparesis. J Phys Ther Sci 2014;26(7):981–3.
56. Ellis RF, Hing WA, McNair PJ. Comparison of longitudinal sciatic nerve movement with different mobilization exercises: An in vivo study utilizing ultrasound imaging. J Orthop Sports Phys Ther 2012;42 (8):667–75.
57. Millesi H, Zöch G, Reihsner R. Mechanical properties of peripheral nerves. Clin Orthop Relat Res 1995; 314:76–83.
58. Gilbert KK, Roger James C, Apte G, et al. Effects of simulated neural mobilization on fluid movement in cadaveric peripheral nerve sections: Implications for the treatment of neuropathic pain and dysfunction. J Man Manip Ther 2015;23(4):219–25.
59. Udina E, Cobianchi S, Allodi I, Navarro X. Effects of activity-dependent strategies on regeneration and plasticity after peripheral nerve injuries. Ann Anat 2011;193(4):347–53.